SCALE ECONOMIES AND CONSOLIDATION IN HOG SLAUGHTER

by

James M. MacDonald
Economic Research Service
U.S. Department of Agriculture

and

Michael E. Ollinger
Economic Research Service
U.S. Department of Agriculture

CES 00-03 March, 2000

Abstract

We use establishment based panel data to estimate a cost function which identifies the role of scale economies in hog slaughter consolidation. We find modest by extensive technological scale economies in the 1990s, and they became more important over time. But wages rose sharply with plant size through the 1970s and those wage premiums generated a pecuniary scale diseconomy that largely offset the effects of technological scale economies. The size-wage relation disappeared in the 1980; with growing technological scale economies and disappearing pecuniary diseconomies, large plants realized growing cost advantages over smaller plants, and production shifted to larger plants.

KEYWORDS: Scale Economies, Consolidation, Hog Slaughter.

JEL Classification: L11

Introduction

U.S. meat and livestock sectors have been transformed in the last two decades. Livestock feeding consolidated as producers who fatten cattle, hogs, and poultry became substantially larger. Far fewer meatpackers now slaughter livestock, but their plants are more specialized and much larger. Finally, exchange relations between producers and meatpackers are changing, with less reliance on spot markets and more reliance on longer term contractual relationships.

Consolidation led to sharply increased concentration in cattle slaughter, and persistent concerns over the future of competition in that industry (USDA, 1996). Hog slaughter has also consolidated, with a dramatic shift toward large plants, and concentration is increasing in that sector as well. This study describes the process of consolidation in hog slaughter, and identifies the role of slaughter scale economies in driving that process. We find that two distinct scale factors are important: technological scale economies, relating to economies of resource use as plant sizes increase, and pecuniary scale diseconomies, relating to changes in labor compensation as plant sizes increase.

Our evidence shows modest but extensive technological scale economies in slaughter in 1992, and those scale economies became more important over time. We also show that wages rose sharply with plant size in the 1960's and 1970's, and that those wage premiums generated a pecuniary scale diseconomy that largely offset the cost effects of technological scale economies. During the 1980's and early 1990's, the size-wage relation disappeared; without that pecuniary diseconomy, and with growing technological scale economies, large plants realized growing cost advantages over smaller plants, and production shifted to larger plants.

Our data offer three distinctive features. First, we analyze slaughter plants in the years from 1963 through 1992, covering a period of rapid industry consolidation. Second, we control for differences in the mix of products at slaughter plants. Product mixes, and their associated in-plant processes and costs, vary both across plants and over time. Accurate estimation of scale relations requires close attention to product mix. Finally, we use data from individual slaughter plants. With a wide cross section of plants in each observed year, we can better identify the extent of scale economies in any year, estimate shifts in scale economies between years, and distinguish pecuniary from technological economies.

The following section describes the process of consolidation in hog slaughter, and compares the process to that in cattle slaughter. We then summarize our model and data, and report our key findings for factor price effects, scale economies, the role of product and input mix, and technological change.

Consolidation in Hog Slaughter

Table 1 describes recent consolidation in hog and cattle slaughter, drawing on reports of the Grain Inspection, Packers and Stockyards Administration (GIPSA) of the U.S. Department of Agriculture (1998). Between 1977 and 1996, plant numbers declined sharply as plant sizes increased. Plants that slaughtered over a million hogs annually accounted for 38 percent of hog slaughter in 1977; two decades later, large plants accounted for 87 percent of slaughter. By 1997, 10 plants accounted for 40 percent of U.S. hog slaughter (USDA, 1998).

Fewer and larger plants mean increases in concentration, although at different rates in each industry. In cattle slaughter, the four firm concentration ratio increased from 28 in 1977 to 68 in 1996, an exceptionally large increase. Hog slaughter concentration grew more modestly, from 34 to 50. Differences in industry growth may account for the differences in concentration change. Commercial cattle slaughter showed no increase after the early 1980's, and by 1995 was still considerably below 1970's slaughter volumes (table 1). But commercial hog slaughter continued to grow through time, and mid 1990's volumes were considerably above prior years.

Structural change in slaughter features two other elements important for our analyses: changes in product mix and in labor relations. Twenty years ago, hog slaughter plants performed multiple functions. They slaughtered hogs, cut up the carcasses, and then processed the pork into bacon, hams, sausages, and other products. But today, modern slaughter plants specialize mainly in hog slaughter and carcass cutting. Many traditional brand-name processors no longer slaughter hogs, but instead purchase cut-up carcasses from slaughter plants for processing.

Important changes in labor relations accompanied industry consolidation. In 1980, 46 percent of meat products industry workers were union members, a figure that had remained stable through the 1970's.[1] Many unionized firms began to press for large base wage reductions, from \$10.69 an hour to \$8.25, levels more consistent with non-union plants. By 1987, after a series of strikes, deunionizations, and plant closings, union membership fell to 21 percent of the workforce, remaining at that level since. Table 1 shows that nominal wages in the industry fell after 1982; accounting for inflation, real wages fell sharply. But the wage distribution also narrowed: large plant hourly wages were 23 percent higher than the industry average in 1977, but that size differential began shrinking in the 1980's, and disappeared by 1992.[2]

A Model of Hog Packer Costs

The shift of output to larger plants suggests scale economies in slaughter. To link scale and consolidation, we need to estimate the extent of scale economies across a wide range of plant sizes, and not simply at mean plant sizes. Moreover, we need a model that can test for scale-increasing technological change. For scale to drive consolidation, large plants should have larger cost advantages in the 1990's than in the 1960's and 1970's.

An analysis of scale economies must take account of product mix. During the period of consolidation, slaughter plants shifted to specialize in slaughter and simple fabrication. Reduced processing lowered plant costs and input demands; if product mix and plant size are related, then failure to control for mix will bias estimates of scale economies.

During consolidation, real wage rates fell sharply, especially at larger plants. We estimate the effects of wage differences on plant costs, in order to identify the role of labor market changes in consolidation. Since the effects are likely to vary with plant production processes (labor should account for a larger share of total costs in plants that do processing, for example), we need to account for differences in labor demand across plants.

For our purposes, we need a statistical cost function that does the following:
a) estimates plant level scale economies, and allows the scale measure to vary with plant size;
b) estimates the effects of product and input mix on costs;
c) identifies the effects of input prices on cost, and allows the effects to vary with plant size;
d) allows effects to vary over time, as a way to capture technological change.

We use the well-known translog cost function, defined as follows:

$$
\begin{aligned}
1)\qquad \ln C = {} & \alpha_0 + \sum \beta_i \ln P_i + (1/2) \sum\sum \beta_{ij} \ln P_i \ln P_j \\
& + \gamma_1 \ln Q + (1/2)\,\gamma_2 (\ln Q)^2 + \sum \gamma_{1i} \ln Q \ln P_i \\
& + \sum \delta_k \ln Z_k + (1/2) \sum\sum \delta_{kl} \ln Z_k \ln Z_l \\
& + \sum\sum \delta_{ik} \ln P_i \ln Z_k + \sum \delta_{1k} \ln Q \ln Z_k \\
& + \sum \alpha_n T_n + \sum\sum \alpha_{in} \ln P_i T_n + \sum \alpha_{1n} \ln Q\, T_n + \sum\sum \alpha_{kn} \ln Z_k T_n.
\end{aligned}
$$

where C is total cost, P is a vector of factor prices (labor, animal and meat materials, capital, and other materials), Q is output, Z is a vector of plant characteristics, T is a vector of dummy variables for each Census year (with 1992 as the base), and ln is the logarithmic operator.

The translog function allows for a variety of possible production relationships including varying returns to scale, nonhomothetic production, and nonconstant elasticities of input demand. Greater efficiency can be obtained by estimating the optimal, cost-minimizing input demand, or cost-share, equations jointly with the cost function. Those equations are the derivatives of total cost with respect to each input price, and share parameters with the cost function:

$$2)\qquad (\partial \ln C)/(\partial \ln P_i) = (P_i X_i)/C = \beta_i + \sum \beta_{ij} \ln P_j + \gamma_{1i} \ln Q + \sum \delta_{ik} \ln Z_k + \sum \alpha_{in}.T_n$$

Because we follow standard practice and normalize all variables (dividing them by their mean values before estimation), the first order terms (the β_i) can be interpreted as the estimated cost share of an input at mean values of the right hand side variables; the other coefficients capture changes in the estimated factor share over time, as factor prices, output, and plant characteristics move away from sample mean values. Since factor shares must sum to one, we drop the capital share equation to avoid a singular covariance matrix. Each equation in the system could be estimated separately by ordinary least squares, but we take account of likely cross equation correlation in the error terms, and follow standard practice by using a nonlinear iterative seemingly unrelated regression procedure.

<u>Measuring Output in the Cost Function</u>

Hog slaughter plants produce a variety of products, and the mix has changed over time. Our data source defines a number of different product categories, including carcasses, hides, primal and fabricated cuts, processed pork products, and byproducts. Each category is itself an aggregate--carcasses may be whole, or in halves or quarters, and fabricated products may cover a wide variety of different cuts.

There are a several ways to include multiple products in a cost function. In principle, we could simply convert Q in the cost function to a vector, with output of each product represented separately. But since many plants do not produce all outputs, and logarithms are undefined at zero, the translog functional form cannot be directly adapted to multiple outputs.

Instead, we follow an approach used in the estimation of transportation cost functions.[3] We define a single output, pounds of meat shipped (Q), but add production characteristics to the equation (this is where the Z vector comes from). Our estimating equation includes a measure of product mix (PMIX), one minus the share of processed pork products in output [4]. PMIX will always be defined in the translog, as processed products never account for all output. Because hide and byproducts are produced in nearly fixed proportions to the number of hogs slaughtered, those shipments account for nearly constant shares of total output. As a result, PMIX varies primarily in proportion to the share of pork processing in a plant's output; increases in processing match declines in the share of carcass and cut-up carcasses. As processing increases, for a given volume of hogs slaughtered, total costs should also increase. Note that PMIX is a reciprocal measure of processing: costs should fall as PMIX increases (we use the reciprocal measure to avoid the zero logarithm problem in the translog).[5]

The estimated cost function yields a natural measure of scale economies, the elasticity of total cost with respect to output, Q:

$$3) \qquad å_{CQ}=(M \ln C)/(M \ln Q)=ã_1 + ã_2 \ln Q + ' ã_{1i} \ln P_i + ' ä_{1k} \ln Z_k + ' á_{1n} T_n$$

Cost elasticities below 1 define economies of scale, while estimated values exceeding 1 show diseconomies of scale. The first order term, $ã_1$, can be interpreted directly as the 1992 cost elasticity estimate for plants at the sample mean size. The parameters on the interaction terms with T (the $á_{1n}$) show how the mean cost elasticity changes through time, while the parameter on the ln Q term (ã2) shows how the elasticity varies as we move away from the sample mean plant size to larger or smaller plant sizes.

We can also define a cost elasticity with respect to changes in processing. The product mix cost elasticity is the derivative of the cost function with respect to PMIX:

$$4) \qquad å_{CZp} = (M \ln C)/(M \ln Z_p) = ä_p + ' ä_{kp} \ln Z_k + ' ä_{ip} \ln P_i + ä_{1p} \ln Q + ' á_{pn} T_n.$$

The first order term, $ä_p$, provides a direct measure of the effect of processing on costs in 1992, at sample means for all variables. That term reports the percentage change in costs attendant upon a one percent change in the share of processing, holding constant the physical volume of output. The interaction coefficients on T, $á_{pn,}$ show how that elasticity changes as one moves back in time. The coefficient on physical output, $ä_{1p}$, provides a measure of scope economies, by allowing the cost elasticity of product mix to vary with plant size.

Recall that PMIX is a reciprocal measure, increasing as processing declines. Therefore, the first order term $ä_p$ should be negative (the greater the carcass share, and the lower the processing share, the lower the costs). Positive values for the scope term $ä_{1p}$ move the $å_{CZp}$ closer to zero in larger plants, so that increases in the processed share of output would have smaller percentage effects on costs in bigger plants. Negative values move the cost elasticity of product mix further from zero, which would mean that increased processing is more costly in bigger plants (economies of specialization in bigger plants).

Our final estimating equation includes two other Z variables, a measure of input mix (IMIX) and a dummy variable for single plant firms. IMIX is the share of hogs in combined live animal and purchased meat input costs. Some slaughter plants purchase additional carcasses from other slaughter plants as inputs to processing lines. Plants with significant amounts of purchased meat may have different cost structures than plants that buy only live hogs.

We observe slaughter plants operating in seven different years: 1963, 1967, 1972, 1977, 1982, 1987, and 1992. The model introduces technological change (Stevenson, 1980), allowing all first-order parameters to vary by adding interaction terms between each first order parameter and each of six different dummy variable (one for each year, with 1992 as the base).

Data and Variable Definitions

We use data from the U.S. Census Bureau's Longitudinal Research Database (LRD). The LRD details the records of individual establishments in the Census of Manufactures in years noted above. LRD hog slaughter plants are not identical to the plants reporting to GIPSA. GIPSA reports on all plants that slaughter hogs and purchase at least $500,000 in livestock. Our LRD file covers plants for whom manufacturing is the primary line of business, hogs are the primary live animal input, Census reporting rules require the filing of detailed data (practically, at least twenty employees), and reported data meet standards for internal consistency. LRD and GIPSA files overlap for midsized and large commercial plants, but the LRD omits a variety of very small plants and other small plants with highly diversified operations (multispecies plants or multiple businesses). The data covered a total of 1,142 plant observations over the seven Census years.

Individual LRD records provide detailed establishment information on product types, quantities, and revenues, material input quantities and expenditures, employment and payroll, and ownership and location. Quantity (Q), product mix (PMIX), input mix (IMIX), and single establishment (EST1) variables were defined above. The model also includes factor prices, for labor (PLAB), meat and animal inputs (PMEAT), other material (PMAT), and capital (PCAP). Precise definitions and sources are in the data appendix.

Model Selection

The model summarized in equation (1) is the most general functional form that we estimated, and is referred to as Model IV. Several more restrictive forms were estimated, to test the assumptions of the model. Model I allows for no technological change and no plant characteristics; in other words, all Model IV variables from the Z and T vectors were dropped, and all á and ä coefficients were set to zero. Model II generalizes Model I by adding product and input mix, and estimating the relevant ä coefficients; Model II does not allow for technological change, since it omits all T variables and thereby sets all á coefficients to zero. Model III adds technological change (the T vector) but continues to omit the single establishment dummy.

Model IV estimates all coefficients in equation 1. Two slightly more restrictive versions of Model IV were also estimated. Model IVA drops all input mix variables (in practice, they are jointly significant but not individually so). Finally, we test for homotheticity by estimating Model IVB, which includes the Z and T vectors but forces factor shares to be invariant to output (that is, the interaction terms between output, Q, and factor prices, the P vector, are dropped).

We applied Gallant-Jorgenson goodness of fit tests to distinguish among the different functional forms. Table 2 summarizes the models and the results of the G-J tests. The most restrictive model (I) was decisively rejected in favor of Model II, which added measures of output and input mix. In turn, Model II was decisively rejected in favor of Model III, which allows all first order coefficients to vary over time. Finally, Model III was rejected in favor of the more flexible Model IV, which added the single establishment dummy variable.

Model IVA restrictions on Model IV were strongly rejected--it's important to account for differences in the mix of animal and meat inputs. Finally, Model IVB was decisively rejected in favor of the more flexible Model IV. The selected Model IV is nonhomothetic and nonhomogeneous, includes measures of product and input mix as well as a shift variable for single establishment firms, and allows all first order coefficients to vary over time. Appendix tables A-1 and A-2 report Model IV's coefficients and t statistics. Table A-1 reports first order coefficients for 1992 and the first order time shifters for earlier years, while table A-2 reports coefficients for quadratic and interaction terms.

Factor price effects

Table 3 reports mean factor shares, calculated with estimated Model IV parameter values and mean 1992 data values (they therefore differ slightly from table A-1's first order factor price coefficients, which are factor shares based for sample mean data values). Live animal and meat inputs account for just over 74 percent of costs (with live animals accounting for almost all of that), while labor carries an 11 percent factor share, other materials 7.8 percent and capital 6.7 percent. The capital share grew over time at the expense of other factors (table A-1). The animal share increases with output, as labor and capital shares decline (table A-2).

The skewed distribution of factor shares carries some important implications. First, changes in hog prices must drive short run changes in total costs and wholesale pork prices. Second, as long as the prices paid for hogs do not decline as plant size increases, substantial scale economies in slaughter and fabrication processes will translate into small scale economies in total costs, because total costs will be dominated by hog purchase expenses.[6] Third, wage changes must have small effects on product prices, because wages form a small share of total costs. Last, wage changes that are not passed through as product price changes can lead to large changes in returns on investment, since labor and capital each form small shares of total cost.

Table 3 also reports price elasticities of input demand, along with Allen elasticities of substitution, using mean 1992 data values. All four inputs have downward sloping demand curves--the estimated elasticities are negative at the mean. The estimated price elasticity of demand for labor is quite close to the estimate reported by Melton and Huffman (1995), while the elasticity on capital is relatively price sensitive. Note that the demand for animal inputs, given meat output, is extremely inelastic--the price elasticity of demand is close to zero. There is essentially no substitution between hogs and labor or between hogs and other materials. There does appear to be some degree of substitution between hogs and capital, reflecting perhaps opportunities to use capital equipment to increase yields of meat from hog carcasses.

Economies of Scale

Recall that our measure of scale economies is the elasticity of total cost with respect to output. The first order coefficient on output, 0.926, shows scale economies in 1992 at the sample mean plant size (table A-1). The elasticity is significantly below one, and the year shifters show that scale economies became more important through time--prior year shift terms are positive and significant. In particular, the mean cost elasticity fell steadily from 1963 to 1977, and then fell sharply again between 1987 and 1992. The coefficient on squared output is positive and statistically significant, moving the cost elasticity closer to one, and constant returns, as plants get larger (table A-2, interaction of Q with itself).

Table 4 provides more precise evidence by reporting cost elasticities for plants at different points of the plant size distribution and at different technology vintages (that is, different years). We chose three technology vintages--1992, 1977, and 1963. We used GIPSA plant size data to select relatively large plants--one at the 95th percentile for each year. We also selected sample mean and annual mean size plants, from LRD plant size distributions. Mean and large plants in 1992 are considerably larger than the corresponding 1977 plants, which are in turn larger than the 1963 plants. For each plant size, table 4 calculates cost elasticities for three different technology vintages, 1963, 1977, and 1992. We can then observe how estimated cost elasticities vary by size of plant for a given year, and by year for a given size of plant.

Four patterns stand out. First, there are modest scale economies. Average sized plants in each year operate in the range of increasing returns--estimated cost elasticities were less than one. Scale economies should be modest, because the slaughter process that generates scale economies accounts for a small share of total costs (that is, the animal share is large). Second, technological change has led to greater scale economies--at any given plant size, one can look across a row and see that the cost elasticity fell from 1963 to 1977, and again from 1977 to 1992. Plants at the sample mean size were producing near constant returns in 1963, but by 1992 would be clearly in a range of increasing returns. Third, the largest plants in each year (those at the 95th percentile of each year's size distribution) were operating at an output level near constant returns. Looking down the diagonal, 95th percentile plants had cost elasticities of 0.98 in 1992, 0.99 in 1977 and 1.01 in 1963. Finally, plant sizes changed to take advantage of scale economies. The largest 1992 plants would have been too large in 1977 or 1963, operating in a range of decreasing returns in the technologies of those years (looking across the row for 1992 95th percentile). Similarly, plants at the 1963 95th percentile would have clearly been too small to take advantage of all scale economies in the 1992 technology.

To facilitate comparisons with other methods, we calculated a slaughter cost per head from our model. We first started with the mean 1992 hog price of $43.03 per hundredweight (Iowa-Southern Minnesota slaughter hog series). Using estimated Model IV coefficients, we calculated the animal share of total costs for a large 1992 plant (4 million head annually)--80.7 percent of total costs, if all 1992 plants paid the same factor prices. Slaughter costs at that plant, 19.3 percent of total costs, would then be 23.9 percent of hog prices, or $10.28 per hundredweight. With a 250 pound hog, that would translate to predicted slaughter costs of $25.70 per head. In turn, 1992 slaughter costs were about $3.50 per head higher at a plant handling 2 million hogs a year, $8.80 higher at a plant handling 1 million hogs a year, and $14.85 higher at the sample mean plant, handling 400,000 head per year. Those estimates compare to Hayenga's (1998) estimates, based on surveys of plant managers, of $23 per head for large plants in 1996-97. Hayenga's estimates are based on operation at full capacity in 1996-97, while ours embody actual 1992 utilization, technology, and factor prices; average costs can rise noticeably as production falls short of capacity.

We are aware of one other statistical study of scale economies in hog slaughter (Melton and Huffman 1995, or M&H). Comparisons are difficult because M&H used aggregate 1963-88 time series data to analyze temporal variations in value added, while we analyze variations in total cost across many plants over 1963-92. They used an unusual output specification, including number of head of animals, average live weight, and number of plants as separate variables. With three separate and unrelated proxies for output, it's hard to define an appropriate cost elasticity, and hard to interpret any proxy-specific elasticity.

M&H report an average value added cost elasticity estimate of 0.79, with respect to number of head while holding weight and plants constant. If value added averages 25 percent of total costs, then that estimate would correspond to a total cost elasticity of .948, which is quite close to our estimates for average size plants at the 1977 midpoint of their data (table 4). But their estimated cost elasticities vary widely from year to year, with 10 percent increases in slaughter numbers being associated with 20 percent declines in total (not average) processing costs in some years, and 20 percent increases in others. M&H also report significant neutral technological change, with steady large trend decreases in costs (5-9 percent per year in value added, or 1 to 2 percent per year in total costs), whereas our cost declines operate entirely though scale economies, factor prices, and mix variables. Increases in output should not reduce total costs, and we suspect that the M&H dataset does not adequately allow for changes in technology, scale, and product mix. We believe that our results are more consistent with observed structural change, and that the panel nature of our data, as well as our output measures, allows for improved results.

Wages and Pecuniary Scale Diseconomies

Industry wages fell between 1982 and 1992, by 5.5 percent (table 1). That decline should have reduced costs by about 0.6 percent, given labor's factor share. But the size differential in wages also disappeared. In 1977, large plant wages were 23 percent higher than the industry mean. At a mean 1977 labor share of 12.8 percent (table A-1), that gap translates into a 1977 cost differential of 2.9 percent, substantially attenuating large plant scale advantages, and moving the largest 1992 plants into the range of diseconomies of scale under 1977 wages and technology.

The wage premia in table 1 are based on aggregated data for all meatpacking plants. Because of the importance of this issue, we looked more closely at hog plant wages. While we cannot report detailed breakdowns of wages by plant sizes, we can report regression results. We ran wage regressions for each Census year, using production worker wages across hog slaughter plants in each year. The dependent variable is the natural logarithm of each plant's average hourly production worker wage, which we regressed on IMIX and PMIX, plant size expressed as number of head (in natural logs), and plant location.[7] Table 5 reports selected results from regressions for four Census years. Coefficients on plant size were large, positive, and statistically significant through 1982. Moreover, unreported coefficients on the Eastern and Western Corn Belt locations were positive, significant, and large. Predicted wages there were substantially higher than in the Southeast and the rest of the country.

The lower panel of table 5 summarizes the estimated premia, reporting regression-based predicted hourly wages at Western Corn Belt (WCB) plants for four years and three different size categories: 400,000 head per year (sample mean), 1 million head (a large plant for 1977) and 4 million head (a large plant for 1992). Compared to the smallest plant, wages at the million head plant were consistently 9-12 percent higher through 1982, and predicted wages at the largest plant were 24-33 percent higher. Now note the regional effect of locating in the Southeast (bottom row); WCB wages are consistently about 50 percent higher than predicted Southeastern wages through 1982. Size and location premia eroded in the unreported 1987 regression, and then disappeared entirely in the 1992 regression--there are no statistically significant differences in 1992 predicted wages, and the coefficient on size is small and not significant.

The size and location premia represented a pecuniary scale diseconomy. In the 1980's and 1990's, those diseconomies disappeared, reinforcing the effect of changing technological scale economies; the timing of their disappearance coincides with sharp increases in plant sizes.[8]

Production Characteristics

Hog plants slaughter hogs and cut up the carcasses into primals, but many also perform further processing into hams, sausages, and other products. Our measure of product mix (1 minus the share of ham and sausage products in output) aims to capture some important distinctions among plants. The measure should be one in plants that only slaughter and fabricate.

The coefficient on PMIX is negative and marginally significant for 1992--plants that do less processing have lower costs, all else equal (table A-1). The coefficient value is not particularly large, again because hog expenses account for so large a share of the total, while processing costs account for small shares. A typical change in product mix toward less processing (from the median 1992 PMIX value to the 75th percentile) would lead to a 1.5 percent reduction in total costs, and therefore in average costs per pound. Changes toward less processing also have effects on factor shares, although only the term involving labor is statistically significant (see the interaction terms with PMIX in table A-2). Labor and other materials account for smaller cost shares in plants that do little processing, as one would expect.

The interaction term between product mix and output is negative, but small and not nearly significant. Thus the data provide no evidence that costs can be reduced by combining processing with slaughter in large establishments; scope economies would also be inconsistent with the observed shift toward separation of slaughter and processing in the hog sector.

Our input mix variable is the value share of hogs in total animal and meat inputs, as distinct from purchased carcasses or, in some plants, from other species. The coefficient on IMIX in 1992 is positive, although small and not statistically significant. But the year shifts are all negative, generally significant, and usually large enough to make the full effect negative in the relevant year (table A-1). The pattern probably reflects changes in IMIX over time. In 1977, for example, many plants specialized only in hogs, but a substantial fraction of sample plants also purchased many carcasses, presumably for processing operations; the median value of IMIX was 90 percent and the 75th percentile value was 100 percent, but the 25th percentile value was 59 percent. As the industry changed over the next 15 years, the distribution of IMIX narrowed to a 1992 median of 98 percent and a 25th percentile value of 91 percent. Given the narrow variance of 1992 IMIX values, it shouldn't be surprising that IMIX has no significant effect on 1992 costs. With wider variations in input mix in earlier years, plants that specialized in hog slaughter more clearly realized lower costs.

Few of the individual coefficients involving IMIX and PMIX are statistically significant. That may reflect multicollinearity; plants that purchase carcasses also do more processing, and when one variable is dropped, coefficients on the other gain significance. But scale economies may be underestimated if product and input mix variables are omitted. Estimated cost elasticities rise by 0.01 to 0.02 when PMIX and IMIX are omitted. Joint tests of significance (table 2) strongly support the inclusion of both measures in the model. We therefore believe that the best estimates of scale economies control for product and input mix.

Finally, note that none of the first order year intercepts in the model are large, none are statistically significant, and there is no particular sign pattern (see the intercepts in table A-1). Temporal changes in slaughter industry costs are accounted for by changes in factor prices (in particular, by hog prices), changes in input and product mix, and by changes in scale economies.

Conclusions and Implications

We find modest but extensive scale economies in hog slaughter. The industry's largest plants can deliver pork products to buyers at costs per pound that are 2-3 percent lower than plants half their size, and 10 percent lower than plants one tenth their size, because their costs of slaughter and fabrication are much lower than the smaller plants.

The industry's recent history strongly suggests that small cost and price differences matter. We find that packers reacted quickly to technological and labor market changes that led to modest increases in available scale economies. But technology and labor cannot be a complete explanation for consolidation. Small, less efficient plants don't exit because larger plants have slightly lower costs: they exit because product prices fall below their own average variable costs. For product prices to be below small plant costs, they must in turn be quite close to large plant unit costs, because we find small differences between small and large plant costs. For modest scale economies to lead to rapid consolidation, the industry must also have had strong price competition.

The period's labor strife also suggests strong price competition. While unionized plants had substantially higher wages than nonunion plants in the 1970's, the effect on costs was small because the share of wages in total costs was small. For small cost differences to have led to plant closures and lockouts, unionized plants would have to have been under strong competitive price pressures from nonunion plants.

If small differences matter, we should expect to see continued industry consolidation: today's largest plants produce near constant returns to scale, but most plants have not exhausted available scale economies. Moreover, if our interpretation is accurate, then other small cost differences, associated with changes in transportation, food safety, and pollution at production stages, can also have important effects on industry structure.

Footnotes

1. Unionization data are calculated from the Current Population Survey, which defines industries at the three digit level. Meat products (SIC 201) includes red meat and poultry slaughter and processing. See Kokkelenberg and Sockell (1985) and Curme, Hirsch and McPherson (1990).

2. Our summary draws on more detailed data in MacDonald, Ollinger, Nelson, and Handy (1998).

Industry wages in table 1 come from published Census Bureau reports for SIC Industry 2011-- cattle, hog, and lamb slaughter plants. We analyze more detailed packer wage data later in this report.

3. Transportation output is often defined simply as ton-miles (see Allen and Liu, 1995, for trucking, or Caves, Christensen, Tretheway, and Windle, 1985, for railroads). But tonmiles can be produced in many ways: shipments can be routed to many different locations, or they can be sent along a few through routes; shipments can also be organized into many small deliveries, or into a few large shipments. Cost functions add measures of route and output characteristics, to capture the multiproduct nature of transport services.

4. Specifically, processed pork products are those assigned to SIC Product Classes 20116 (Pork, processed or cured) and 20117 (Sausages and similar products). These are reported separately from the largest hog plant Product Class, 20114 (Pork, fresh and frozen).

5. We also tried a multiple product cost function, with separate entries for pounds of carcass, fabricated, and processed products, while setting zero outputs to low but positive values. That form provided a weaker fit than our preferred alternative, and we are wary of inserting arbitrary values into our model. We estimated a model with SIC Classes 20116 and 20117 entered as two separate PMIX variables. Finally, we defined PMIX as the relative value of output, with those plants obtaining a higher value of shipments per pound of output in any year assumed to have a more complex product mix. All specifications gave similar qualitative results, but our final choice provided the best fit to the data and a more direct interpretation.

6. We looked for associations between plant size and hog prices in our data. The LRD is not an ideal source for analyzing hog price determinants, because it has no measures of animal characteristics aside from average weights. We did find that larger plants and firms with higher market shares consistently paid higher prices for hogs, in regressions that also controlled for input and product mix, region, and year. Those results reinforce the assertion in the text, that scale economies must be small if hog acquisition costs are a large share of total costs.

7. Increased plant sizes may require substantial increases in fixed capital investment--note the increased capital shares in table 3. Labor in large plants may also be a fixed input in the short run over significant ranges of output (Hayenga, 1998). In turn, higher fixed costs could lead to stronger incentives to reach optimal capacity utilization, because of sharp increases in short run average costs as output falls below capacity. Then the change in plant sizes could have led to shifts in contracting arrangements toward greater vertical coordination, as a tool to manage capacity utilization. Since our Census data do not describe procurement methods, we are unable to investigate that hypothesis.

8. We used regional dummy variables for plant location, with the regions being Eastern Corn Belt (IL, IN, MI, OH, and WI), Western Corn Belt (IA, KS, MN, MO, ND, NE, SD), Southeast (FL, GA, KY, NC, SC, TN, VA), Northeast (CT, DE, MA, MD, ME, NH, NJ, NY, PA, RI, VT), and the rest of the country. We chose a log-linear specification because it clearly gave the best fit; in particular, the size-wage relation was best represented by a log-linear functional form.

Table 1: Structural Change in Cattle and Hog Slaughter Plants

	1977	1982	1987	1992	1996
Hog Slaughter Plants	-Number of Plants Reporting to GIPSA-				
Large	22	35	32	34	32
Medium	114	95	60	53	43
Small	333	336	259	213	157
Large Plant Importance	-Large Plant Share of Slaughter Reported to GIPSA-				
Hogs	38	59	72	86	87
Cattle	12	28	51	61	65
Concentration	-Four Largest Firms' Share of Slaughter Reported to GIPSA-				

Hogs	34	36	37	44	50
Cattle	28	32	54	64	68
Commercial Slaughter	-Millions of Animals, Three Year Average-				
Hogs	76.1	87.1	82.9	92.0	93.4
Cattle	41.4	35.8	36.0	33.0	36.2
Average Packer Wages	-Dollars per Hour, Production Workers-				
Industry Wide Mean	6.86	9.06	8.27	8.56	n.a.
Large Packing Plants	8.44	10.00	8.50	8.65	n.a.

Notes: Concentration, plant count, and large plant data are from U.S. Department of Agriculture, Grain Inspection Packers and Stockyards Administration (GIPSA). Large cattle plants slaughter at least 500,000 cattle a year, while large hog plants slaughter at least one million annually. Small hog plants slaughter less than 50,000. Commercial slaughter is from U.S. Department of Agriculture, National Agricultural and Statistics Service (NASS). Wage data are from Census of Manufactures, production worker payroll divided by hours. The data refer to SIC 2011, which includes cattle, hog, lamb, sheep, and calf slaughter plants; large plants in the wage data have at least 1,000 workers.

Table 2: Tests of Model Selection, Hog Slaughter Cost Function

Comparison, Unrestricted vs. Restricted	Comments	Test statistics d.f.	critical value @ .99	Chi-square
II vs. I	Model I has factor prices and output only; Model II adds product and input mix	13	27.69	98
III vs. II	Model III adds first order time shifters	42	66.18	89

IV vs. III	Model IV adds single establishment dummy to III	7	18.48	36
IV vs. IVA	Model IVA drops input mix from IV	19	36.19	109
IV vs. IVB	Model IVB imposes homotheticity on IV	3	11.34	136

Notes: Chi-square calculations are the difference in Gallant-Jorgenson statistics in the estimated models.

Table 3: Mean Input Shares and Elasticities in Hog Slaughter

	Input Price Variables			
	PLAB	PMEAT	PMAT	PCAP
Input Shares	.1121	.7426	.0779	.0674
åii	-0.347	-0.076	-0.196	-1.385
óij (Allen)				
PLAB	-3.098	-0.118	3.475	2.443

PMEAT	-0.102	-0.246	1.602
PMAT		-2.510	-0.143
PCAP			-20.55

Note: All values are calculated using mean 1992 data values and parameters from tables 3 and 4. The own price input demand elasticities (å$_{ii}$) are calculated holding output and other factors constant, while the elasticities of substitution (ó$_{ij}$) are calculated using Allen's formula.

Table 4: Cost Elasticities for Differing Plant Sizes and Technology Vintages.

	Technology Vintage		
Plant Size	1992	1977	1963
Sample Mean	0.926	.9549	.9856

1992 Mean	0.956	0.985	1.016
1992 Large Plant	0.983	1.012	1.043
1977 Mean	0.924	0.953	0.984
1977 Large Plant	0.958	0.987	1.017
1963 Mean	0.911	0.946	0.971
1963 Large Plant	0.950	0.979	1.009

Notes: Cost elasticities are derivatives of the total cost function (Model IV, tables A-1 and A-2) calculated at different output levels and technology vintages. Output levels are derived from GIPSA (1998) data on plant size distributions.

Table 5: Selected Results from Plant Average Wage Regressions

Year	1963	1972	1982	1992

Coefficient and t statistic on ln (# of head)		.094 (8.40)	.104 (7.54)	.122 (6.93)	.019 (0.91)
Plant Characteristics					
# of Head	Location	-Predicted wages per production worker hour-			
400,000	WCB	3.08	5.04	12.17	8.08
1,000,000	WCB	3.36	5.54	13.61	8.22
4,000,000	WCB	3.83	6.40	16.11	8.44
4,000,000	South	2.59	4.20	10.83	8.02

Note: Based on regressions of plant average production worker wages (in natural logarithms on plant size (number of head, in logs). The model also included controls for input mix, product mix, and plant location (eastern corn belt, western corn belt (WCB above), northeast, south, and rest of country).

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Data Appendix: Definitions and Sources for the Cost Analysis

All variables, except for capital rental prices, are derived from the Longitudinal Research Database (LRD) maintained at the Center for Economic Studies of the U.S. Census Bureau. Total cost (COST) is the sum of labor, meat, material, and capital input costs. Meat input prices (PMEAT) are defined as expenses for meat and animal inputs, divided by total pounds of meat and animal inputs. The price of labor (PLAB) is total plant labor costs (payroll plus supplemental labor expenses) per employee. The materials price (PMAT) is total annual expenses for packaging, energy, and other nonanimal and nonmeat materials, divided by pounds of animal and meat inputs. The capital price (PCAP) is defined as (OPPORTUNITY +NEW)/(CAPACITY), where OPPORTUNITY is the sum of machinery and structures rental values multiplied by their respective book values, NEW is the cost of new equipment and structures, and CAPACITY is equipment and machinery book value, minus retirements. Annual capital rental prices are calculated by the Bureau of Labor Statistics for buildings and machinery in Food and Kindred Products, using methods described in U.S. Department of Labor (1983).

Output (Q) is defined as pounds of meat products (products assigned to SIC industry code 2011) shipped from the hog slaughter plant in a year. Product mix (PMIX) is Q minus pounds of processed pork (products assigned to SIC product class codes 20116 and 20117, which are components of the 2011 category), divided by Q. Input mix (IMIX) is the pounds of live hog inputs purchased by a plant in a year, divided by the combined pounds of hog and meat inputs.

In the wage analysis, WAGE is annual production worker payroll divided by annual production worker hours. HEAD is annual number of hogs slaughtered.

Appendix Table A-1: Hog Slaughter Cost Function Parameters: First Order Terms and Year Shifts

	Coefficients and Standard Errors						
	1st Order	Changes from 1992					
Variables	1992	1963	1967	1972	1977	1982	1987
Intercept	-.1034	-.0180	-.0188	.0315	.0436	.0006	-.0327
	(.0363)	(.0423)	(.0413)	(.0413)	(.0418)	(.0441)	(.0429)
PLAB	.1127	.0112	.0218	.0180	.0151	.0158	-.0007
	(.0081)	(.0089)	(.0090)	(.0093)	(.0093)	(.0096)	(.0099)
PMEAT	.7263	.0373	.0642	-.0036	.0339	.0032	-.0103
	(.0420)	(.0455)	(.0458)	(.0467)	(.0475)	(.0506)	(.0529)
PMAT	.0805	.0184	.0211	.0105	.0087	.0088	.0056
	(.0059)	(.0065)	(.0065)	(.0067)	(.0068)	(.0070)	(.0072)
PCAP	.0805	-.0668	-.1081	-.0249	-.0577	-.0277	.0054
	(.0449)	(.0486)	(.0490)	(.0499)	(.0509)	(.0541)	(.0566)
Q (lbs)	.9259	.0597	.0641	.0418	.0290	.0398	.0368
	(.0184)	(.0212)	(.0210)	(.0214)	(.0217)	(.0221)	(.0218)
PMIX	-.0346	.0110	.0088	-.0339	.0005	-.0167	-.0221
	(.0236)	(.0191)	(.0212)	(.0206)	(.0191)	(.0187)	(.0194)
IMIX	.0326	-.0130	-.0503	-.0420	-.0447	-.0851	-.0623
	(.0284)	(.0267)	(.0267)	(.0280)	(.0270)	(.0293)	(.0295)

Note: Results of estimation of translog cost function for hog slaughter plants, 1963-1992. Since all variables are standardized at their means, first order coefficients can be interpreted as elasticities at the sample means, while year shifts capture shifts in those elasticities over time.

Appendix Table A-2: Hog Slaughter Cost Function Parameters: Higher Order Terms

		Interactions with:							
Variables	1st order	PLAB	PMEAT	PMAT	PCAP	Q (lbs)	PMIX	IMIX	EST1
		Coefficients and standard errors							
PLAB	.1127	.0606	-.0931	.0216	.0109	-.0248	-.0030	.0004	-.0150
	(.0081)	(.0044)	(.0043)	(.0020)	(.0035)	(.0015)	(.0010)	(.0010)	(.0047)
PMEAT	.7263		.1349	-.0721	.0302	.0346	.0022	.0074	-.0056
	(.0420)		(.0132)	(.0028)	(.0142)	(.0060)	(.0042)	(.0045)	(.0210)
PMAT	.0805			.0566	-.0060	-.0025	-.0010	.0028	-.0042
	(.0059)			(.0017)	(.0024)	(.0010)	(.0007)	(.0008)	(.0034)
PCAP	.0805				-.0305	-.0073	.0018	-.0068	.0248
	(.0449)				(.1006)	(.0064)	(.0045)	(.0046)	(.0224)
Q (lbs)	.9259					.0246	-.0030	.0058	.0197
	(.0184)					(.0053)	(.0030)	(.0043)	(.0123)
PMIX	-.0346						-.0043	.0028	-.0023
	(.0236)						(.0040)	(.0017)	(.0107)
IMIX	.0326							-.0023	.0215
	(.0284)							(.0027)	(.0139)
EST1	-.0214								
	(.0268)								

Note: Quadratic (on diagonal) and interaction terms from estimation of translog cost function. First order terms from table A-1 are repeated in first column.

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